Scale-Up of Carbon/Carbon Composite Bipolar Plates

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Subcontractor: UTC Fuel Cells, Inc., South Windsor, CT

Objectives

- Develop carbon/carbon composite materials for bipolar plates that meet or exceed targets
- Evaluate the performance of the bipolar plate materials through fuel cell stack testing
- Design and construct a research-scale production line for materials development efforts
- Design and construct a pilot-scale production line to demonstrate high-volume, low-cost bipolar plate manufacturing

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year R,D&D Plan:

- O. Stack Material and Manufacturing Cost

Approach

<u>Phase I</u>

- Design, construct and install material forming, pressing and thermal treatment equipment
- Systematically investigate material forming techniques and composition ingredients
- Systematically investigate material processing variables and test material properties
- Perform fuel cell testing to evaluate plate performance at UTC Fuel Cells
- Investigate forming techniques aimed at rapid, low-cost production

<u>Phase II</u>

- Design, construct and install pilot-scale production line for 300 plates per hour capacity
- Design and implement quality assurance system for pilot line
- Evaluate pilot line performance and estimate pilot and mass bipolar plate production costs
- Evaluate pilot line bipolar plates for fuel cell performance and deliver fuel cell stack

Accomplishments

- Completed numerous fuel cell tests at UTC Fuel Cells, gathering invaluable information regarding material design and functionality
- Completed installation and demonstration of Phase I development line
- Expanded line to manufacture materials in higher volumes to meet near-term demands for product

- Developed extensive quality assurance system to complement near-term product manufacturing (quality system audited by UTC Fuel Cells)
- Began investigation into Phase II pilot production line processes; identified key process bottleneck areas in Phase II line
- Developed detailed timeline and organized plan for Phase II line implementation
- Continued development of improved bipolar plate materials

Future Directions

- Continue fuel cell testing at partner site
- Continue product development activities
- Initiate Phase II line process investigations to address specific process bottlenecks
- Accelerate Phase II line design and installation activities
- Continue to develop materials and processes to increase product yield and product sensitivity to raw material and process variation

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Introduction

In April 2001, Porvair Fuel Cell Technology, Inc. (PFCT) licensed a carbon/carbon composite bipolar plate formation technology from Oak Ridge National Laboratory. The goal of PFCT is to transfer this technology from the laboratory to full-scale, low-cost mass production to meet the emerging need of the rapidly developing fuel cell industry. This project is directed at further developing the carbon/carbon bipolar plate material to meet the performance, durability and cost demands of the fuel cell industry, and demonstrating a pilot-scale manufacturing line to produce this material in reasonable pilot quantities (300 plates per hour) at low cost.

Approach

The path to final production demonstration is split into two major parts in this project. Phase I focuses upon material and composition refinement to satisfy the fuel cell property and performance requirements. Phase II focuses upon the design, installation and operation of a fully functional bipolar plate production line capable of demonstrating high speed, low cost plate manufacturing.

The approach taken in materials development utilizes information fed back to PFCT by our customers following product property and fuel cell testing. Specific needs and concerns of our customers are evaluated relative to the current state of the product or process development to guide improvements leading toward a better bipolar plate. Internally, materials development efforts are guided through the performance of statistically designed experiments. Key product or process variables are evaluated in an orthogonal array of experiments. Results are measured and analyzed to determine the degree of influence each variable has on the measured property. A statistical model is then built to aid in moving subsequent experiments into a near-optimum range of investigation.

The approach utilized in planning the Phase II production line utilizes external contract engineering assistance along with internal process development activities. A local engineering house has been contracted to assist with Phase II project planning and execution. The execution plan schedules specific milestone events, including the development of an overall project outline, the development of key Process Instrumentation and Control, Process Flow and Plant Layout Diagrams, the development of the governing quality system and the basics of plant layout and construction (tear-down and clear-out, utility plan, environmental permitting, equipment specifications and bids, etc.).

Results

Phase I of the project has been completed in the past year. Our Phase I objectives were met, including development of materials with properties that exceed DOE targets and successful fuel cell testing through our commercial partner, UTC Fuel Cells. Further, because of the strong interest in the product, activities were performed to expand the Phase I development line, and quality system development activities were implemented for this line. PFCT and our customers provided the funds used to expand the Phase I line.

Figures 1 and 2 show some of the expanded Phase I equipment. The accelerated manufacturing of the product enabled PFCT to accelerate the learning associated with product and manufacturing

Figure 1. Expanded Development Equipment Used In Bipolar Plate Manufacture - Forming

Figure 2. Development Equipment Used in Bipolar Plate Evaluation - Laboratory

issues. These include raw material specification fit to the product, impurities and supply capability, and process variability and its effect on product properties and product yields. Much of this experience will transfer directly to the Phase II line and enable faster implementation of that line.

Materials development activities continued in 2003 with the goal of continued materials properties improvement and cost reduction. Through materials development efforts, electrical conductivity was increased while maintaining flexural strength, formability and low hydrogen permeability. Table 1 shows the properties relative to DOE targets. Conductivity, strength and material purity (all carbon product) are the key advantages of the material developed at PFCT. Figures 3 and 4 show the range of conductivity and strength achieved versus final

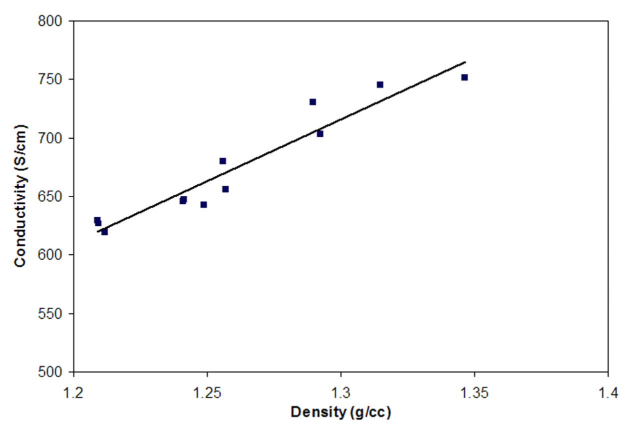

Figure 3. Product Conductivity as a Function Of Density

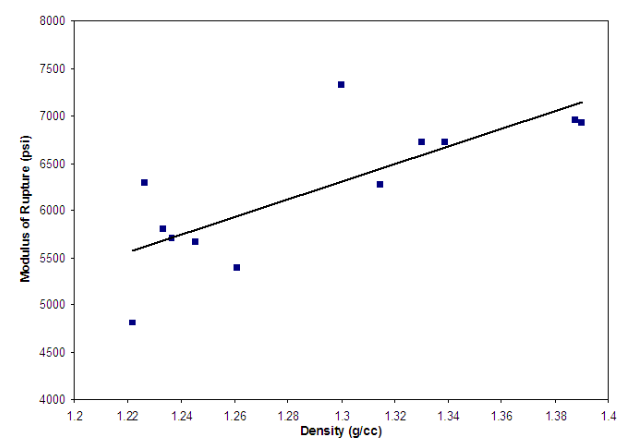

Figure 4. Product Strength as a Function of Density

Table 1. Carbon/Carbon Material Properties

Property	Value	DOE Target
Electrical Conductivity (S/cm) (ASTM C611)	> 600	> 100
Density (g/cc)	1.00 - 1.30	-
Flexural Strength (psi)	>5000	> 600 (crush)
Flexibility (%)(deflection at mid-span)	1.5 - 3.5	3-5
Hydrogen Permeability ($cc/cm^2/sec$) (ASTM D1434)	$<2x10^{-6}$	$<2x10^{-6}$

product density, respectively. The conductivity of the product greatly exceeds that of competitive low-cost bipolar plate materials. Different bipolar plate designs have been fully embossed using the developed materials with good success, demonstrating the potential of this material in the manufacture of low-cost plates.

In manufacturing products, sealing against hydrogen occurs through the chemical vapor infiltration process. In this process, carbon is deposited from a hydrocarbon gaseous precursor such that a hermetic skin is formed on the surfaces of the product. This yields a product that is sealed at a much lower overall density than competitive bipolar plates. Figure 5 is a micrograph of the sealed region of the product.

Numerous fuel cell tests have been performed at UTC Fuel Cells to date. The goals have been focused at both investigating the product for basic performance and evaluating aspects of the product for acceptable fuel cell performance and durability. Both single cell and multiple cell testing has occurred. Much of this testing has been funded by UTC Fuel Cells, independent of this development project. Positive test results have led to a strong demand for the product, but specific data are proprietary. The chart shown in Figure 6 shows qualitatively the performance improvements that PFCT products have been able to achieve over the course of the project. In general, the number following Porvair in the chart is chronological. Later products performed well against the bill of material

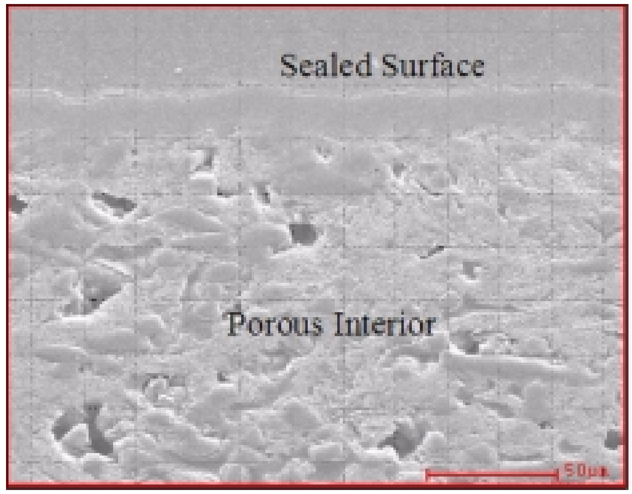

Figure 5. SEM Micrograph of a Molded Carbon/Carbon Composite Material (Figure shows thin skin coating on plate exterior to provide plate sealing.)

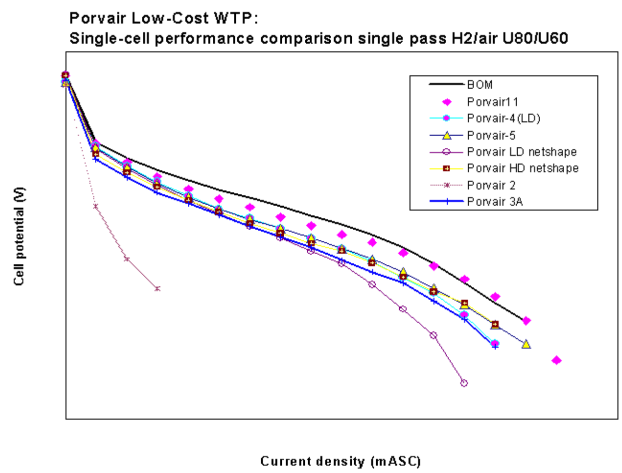

Figure 6. Polarization Curve Showing PFCT Materials in UTC Fuel Cells Testing Relative to Bill of Material (BOM) Target (Numbers in chart reference product trials in approximate chronological order.) WTP = water transport plate; LD = low density; HD = high density; ASC = a/cm^2

machined graphite. Specific test results have been used by UTC Fuel Cells to evaluate product performance relative to competitive products and plate design. Specific feedback to PFCT has been used to guide product design and process changes to yield a better performing and more consistently manufactured product.

Specific work has been done toward the Phase II line, including up-front planning and process scale-up development. Specific portions of the process, where equipment cost is prohibitive or where line bottlenecks exist, are receiving attention to simplify the required equipment and increase the processing time for that portion of the manufacturing cycle. A plan has been developed to investigate these processes to yield equipment specifications so that the necessary equipment can be ordered and installed for Phase II.

The Phase II line will be semi-automated, where key processes are monitored and controlled with calibrated electronic equipment. Component transfer will be through use of conveyors or simple robotics where such operations are not complex. Initial cost analyses have been performed to evaluate the cost-effectiveness of the line. As with any manufacturing process, final product cost depends greatly on the yield of the manufacturing line. The line implementation plan anticipates low yields to start, increasing to optimum levels over the first 4-6 months of line operation.

Conclusions

Porvair Fuel Cell Technology has continued to develop materials and manufacturing processes to supply high quality bipolar plates to the fuel cell industry. Advancements in the past year have included continued mass manufacturing process investigation and Phase II production line planning.

In addition, due to product demand, the laboratory system has been expanded, and a complete quality assurance system has been developed and implemented for this development line. The quality system will serve as the backbone for the Phase II production line.

Fuel cell tests of PFCT's bipolar plate products have continued at a rapid rate at UTC Fuel Cells, as the products are evaluated for beta and pre-production units. Tests have taken place in single-cell, multi-cell and full stack arrangements.

Special Recognitions & Awards

1. Federal Laboratory Consortium for Technology Transfer, Excellence in Technology Transfer Award